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THESIS

THE ARTILLERY FIRE DIRECTION CENTER SIMULATION

by

Ilias Svarnas

September 2003

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In recent years, declining budgets, limitations on artillery ammunition and decreases in training areas have reduced the opportunity to conduct live fire artillery training. For these reasons, simulation systems are available for providing an almost realistic training platform for the forward observer. One of them is "The Forward Observer Personal Computer Simulator (FOPCSIM)", which is the thesis work of two students, David Brannon and Michael Villandre. FOPCSIM is a useful tool for the training of the forward observer without major requirements. However, it is a stand-alone system and many of the actual procedures of the observed fire are provided by the system. This thesis presents another system which simulates the Fire Direction Center procedures during a firing mission. The two systems have a network communication for exchanging messages similarly with the real communication messages between the forward observer and the FDC. Now, the training of the forward observer is more realistic because this person must take into account the existence of the FDC, must wait for responses for each message sent out, and must deal with problems such as communication errors, time delays in sending and receiving messages, and modifications in the call for fire from the FDC. The new system will provide feedback by keeping a history of each mission and giving the observer the capability to review the process of each mission and make useful conclusions about performance.

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THE ARTILLERY FIRE DIRECTION CENTER SIMULATION

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ABSTRACT

In recent years, declining budgets, limitations on artillery ammunition and decreases in training areas have reduced the opportunity to conduct live fire artillery training. For these reasons, simulation systems are available for providing an almost realistic training platform for the forward observer. One of them is “The Forward Observer Personal Computer Simulator (FOPCSIM)”, which is the thesis work of two students, David Brannon and Michael Villandre. FOPCSIM is a useful tool for the training of the forward observer without major requirements. However, it is a stand-alone system and many of the actual procedures of the observed fire are provided by the system. This thesis presents another system which simulates the Fire Direction Center procedures during a firing mission. The two systems have a network communication for exchanging messages similarly with the real communication messages between the forward observer and the FDC. Now, the training of the forward observer is more realistic because this person must take into account the existence of the FDC, must wait for responses for each message sent out, and must deal with problems such as communication errors, time delays in sending and receiving messages, and modifications in the call for fire from the FDC. The new system will provide feedback by keeping a history of each mission and giving the observer the capability to review the process of each mission and make useful conclusions about performance.

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I. INTRODUCTION

A. PROBLEM STATEMENT

In recent years, there has been a large reduction in the availability of artillery training ammunition. There has also been a reduction in the number of training areas that allow the firing of artillery ammunition. In addition, many restrictions have been placed on the firing of artillery ammunition in the remaining training areas. For example, during many months of the year, the chances of starting a wildfire from exploding artillery shells prohibit any live fire training. At other times, the close proximity of populated civilian areas, limits the time of day that artillery can be fired due to noise restrictions. Additionally, the presence of endangered wildlife species along with environmental and safety concerns surrounding the firing of various artillery munitions, such as white phosphorus and improved conventional munitions, severely limits artillery live fire.

Budget reductions and limitations of live fire opportunities have adversely affected the proficiency of the forward observer. For these reasons, an alternative method for training the forward observer must be found to provide almost realistic environments in order to accomplish the fire missions. One solution is to develop and use a computer simulation system in order to enhance training and operations.

Many such simulations, for the training of the forward observer, do exist and provide an alternative method, but when and where the live fire opportunities exist are rare. One method is the work of two students in the Computer Science Department at the Naval Postgraduate School in September 2002. In their thesis, they developed the Forward Observer Personal Computer Simulator (FOPCSIM). Their goal in developing the FOPCSIM was to provide training for the forward observer at the battery and battalion level in such a way that the only equipment required was a PC currently available at the unit level.

The result was a very good stand alone simulation for forward observer training, using modern technology with geographic and digital elevation data that appeared to be very realistic as shown in Figure 1.

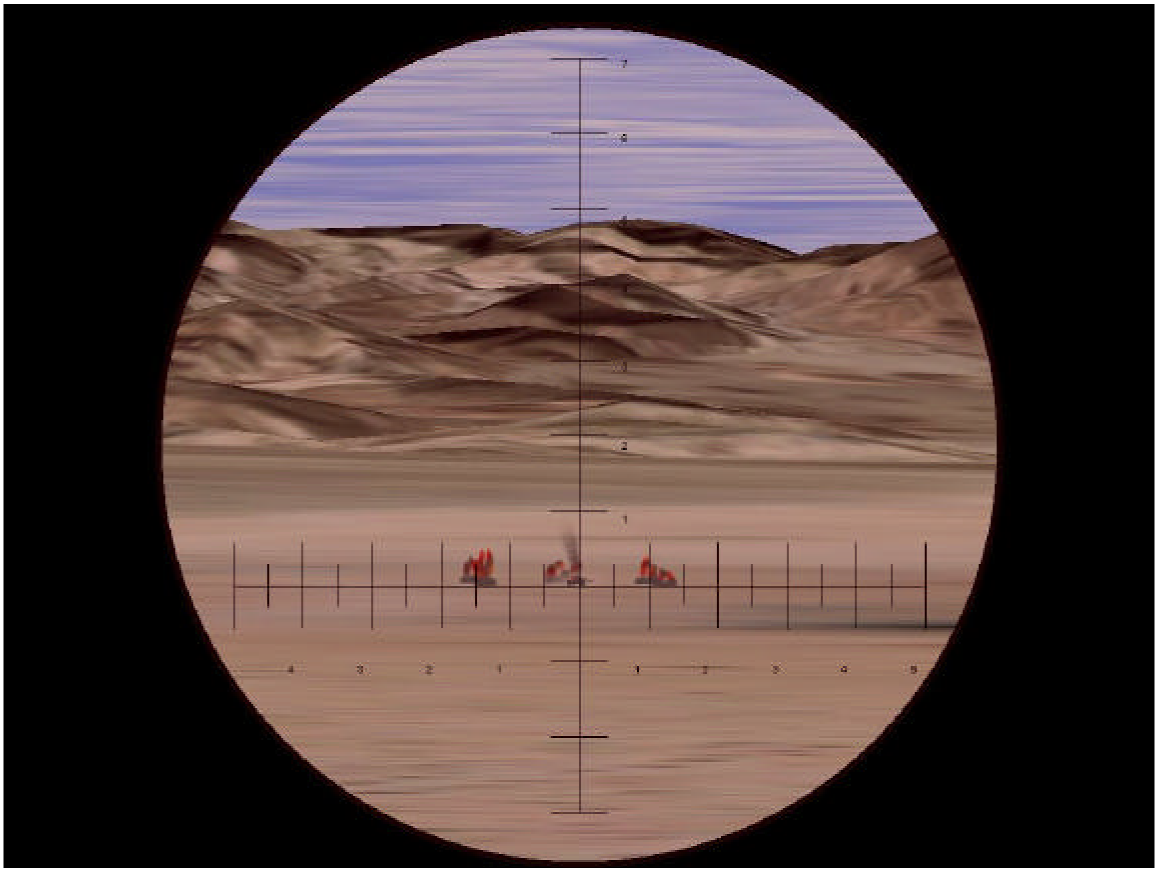


Figure 1. Screenshot from the FOPCSIM

The computer requirements for the FOPCSIM are minimal, and can run on a stand-alone PC.

However, its performance is somewhat limited as described below.

- The responses of the battery's Fire Direction Center (FDC) are assumed and they are always correct and provided by the system. This makes the system a little unrealistic. In reality, the artillery firing procedure consists of many elements that make it quite difficult. One of them is communications. Artillery in general use communication systems extensively, such as telephone lines, radio systems and so forth. Thus, if the communication between the forward observer and the FDC is not working well, the firing mission cannot be completed successfully. Errors that occur during the communication resulting in erroneous firing projectiles must also be taken into consideration.
- Another element of the system is the expected explosion of the fired projectile. In the FOPCSIM, the explosion occurs instantly when the observer presses a specific key. Thus, the time of the explosion is known. In reality, the observer is informed that the cannons have fired the

projectile, as well as the expected time of the flight of the projectile until the impact on the ground.

- Lastly, the location of the explosion is exact and it is the location of the target as estimated by the observer. No gunnery computations take place. In reality, the FDC takes the location of the target from the observer and makes all the gunnery computations using special equipment or firing tables in order to calculate the firing data. These data are given to the battery which properly adjusts the firing cannons. Furthermore, no two projectiles with the same firing elements from the same cannon will explode in the same location. There are various parameters, mostly atmospheric, that affect the projectile during its flight towards the target.

B. MOTIVATION

For the above reasons, a need exists for creating a more realistic simulation which will have situations as they appear in real time training and operations. The goal of this thesis is to create another application which will simulate the Fire Direction Center of the artillery battery. This application will communicate with the FOPCSIM and the two applications will exchange messages simulating a Call for Fire as it happens in real time.

The forward observer who will be trained in the FOPCSIM will have to take into account the existence of the FDC, which will receive the observer's messages and will respond to them by accepting or rejecting various aspects of the call for fire.

The FDC application will have the ability to accept calls for fires from up to three forward observers as happens in real time. Each battery has one FDC and three forward observers.

C. RESEARCH QUESTIONS

This research attempts to answer several key questions.

First, what functions of the FOPCSIM that are part of the FDC can be isolated and included in the proposed simulated FDC? The user of the FDC application will now send all the messages that the FDC sends to the observer and were produced by the FOPCSIM itself.

Second, what other functions of the FDC can be implemented in the proposed system? Some of them are the record of the entire call for the fire procedure. The FDC uses the DA Form 4504 for recording the call for fire, as shown in Figure 4. Also, the FDC keeps a map of the area on which the positions of various elements are drawn, such as the observers, the battery, the targets and so forth.

Lastly, how will the communication between the two systems be implemented to create a more realistic training system for the observer, and how will the proposed system react to specific problems such as the loss of communication, a delay in message delivery and so forth? The system will be a peer to peer network system with the FDC application acting as a host and the FOPCSIM as a client. The FDC will create a communication session and each FOPCSIM client will establish a connection to that session in order to start a call for fire. The exchange of messages will be done strictly between the FDC and each FOPCSIM client. Furthermore, the exchange of messages is a one to one function. The messages that leave the FOPCSIM client will be received only by the FDC. Similarly, the FDC will send messages to a specific FOPCSIM client and not to all those connected.

II. BACKGROUND

A. INTRODUCTION

1. The FOPCSIM Application

The Forward Observer Personal Computer Simulator (FOPCSIM) is a PC desktop application whose purpose is to provide training for the forward observer of the artillery.

The only equipment required is a Personal Computer, loaded with the program and the required components (VEGA® run-time license, terrain data, 3D models, etc.).

The application provides the trainee with a user interface in which the target area is represented using a 3D terrain model. After the program initializes, the set-up screen will appear, as demonstrated in Figure 5. The user should choose the appropriate settings via the left mouse button and will then be ready to start the training. The user is assumed to be standing on an observation post, facing the area where the targets will appear. Utilizing the mouse by clicking and dragging, the user can rotate the view a full 360 degrees. Radio transmissions appear at the bottom of the screen. The supporting firing battery has the user's position and is ready to receive fire missions. By pressing some special function keys, the user can change the view as follows:

[F3]: Binocular view.

[F4]: MULE view, to measure direction, range and vertical angle.

[F5]: Handheld Laser Range Finder (AN/GVS-5) view, to measure range.

[F6]: Compass view gives magnetic direction by placing the cross hair on the target or terrain feature and reading the direction, in mils, from the dial below.

[F7]: Handheld Global Positioning System (GPS) view yields a 10-digit grid to the user's position accurate to one meter.

When the user is oriented to the impact area, it is time to engage a target. After a target appears by pressing the [F10] function key, the user must use the mouse to pan left and right and may utilize the viewing devices described previously to locate the target.

When the target has been located, the user starts the call for fire procedure, to be described later, using different keyboard keys for different messages. An example of a sample call for fire follows.

Warning Order:

Select [P] for Adjust Fire Polar mission.

Select [O] to send transmission to firing unit.

Read radio transmissions at the bottom of the screen.

Target Location:

Select [D] for direction, followed by four-digit direction.

Select [R] for range, followed by four-digit range.

Select [O] to send transmission to firing unit.

Read radio transmissions at the bottom of the screen.

Target Description/Munitions Requested:

Select [T] for target followed by a single digit for target description.[1]

Select [M] for munitions followed by single digit for munitions type.

Select [O] to send transmission to firing unit.

Read radio transmissions at the bottom of the screen.

Message to observer (MTO) from firing unit appears.

Subsequent Adjustments:

Upon receiving the MTO, the firing unit is ready to fire and the user should be ready to observe the first adjusting round. The round will impact upon selecting [S] for shot. Upon viewing the impact, the user must send subsequent adjustments to the firing unit to move the impact onto the target using the arrow keys followed by a digit which represents an adjustment.

[1] Description of digit codes can be found on the FOPCSIM instructions manual.

When the adjustment is expected to place the next impact within 50 meters of the target, the user should enter the Fire for Effect (FFE), by selecting [F] for Fire for Effect followed by [O] to send the transmission. When [S] for shot is selected, the user will see a six-round circular sheaf. If effects on the target are achieved, the user may end the mission by selecting [E] for end of mission followed by [O] to send the transmission.

During this procedure, the responses of the firing battery are automatically provided to the user, and appear at the bottom of the screen. In real conditions, these responses as well as other actions are performed in the Fire Direction Center of the firing battery as will be described in the following paragraph.

B. THE FIRE DIRECTION CENTER (FDC)

1. FDC Organization

The organization of the FDC must allow for the accomplishment of the following goals:

- Continuous, accurate, timely, and safe artillery fire support under all weather conditions and terrain.
- Ability to engage all types of targets over a wide area.
- Massing of fires of all available units within range.
- Processing simultaneous missions.
- Dissemination of pertinent information.
- Efficient division of duties.
- Adherence to standard techniques and procedures.
- Teamwork and adherence to a definite specified sequence of operations to avoid and eliminate errors and to save time.
- Efficient use of communications.

The FDC consists of personnel and special equipment for the successful execution of the calls for fire given by the forward observers. Figure 2 shows a typical organization of the battery FDC with the position of each person in it.

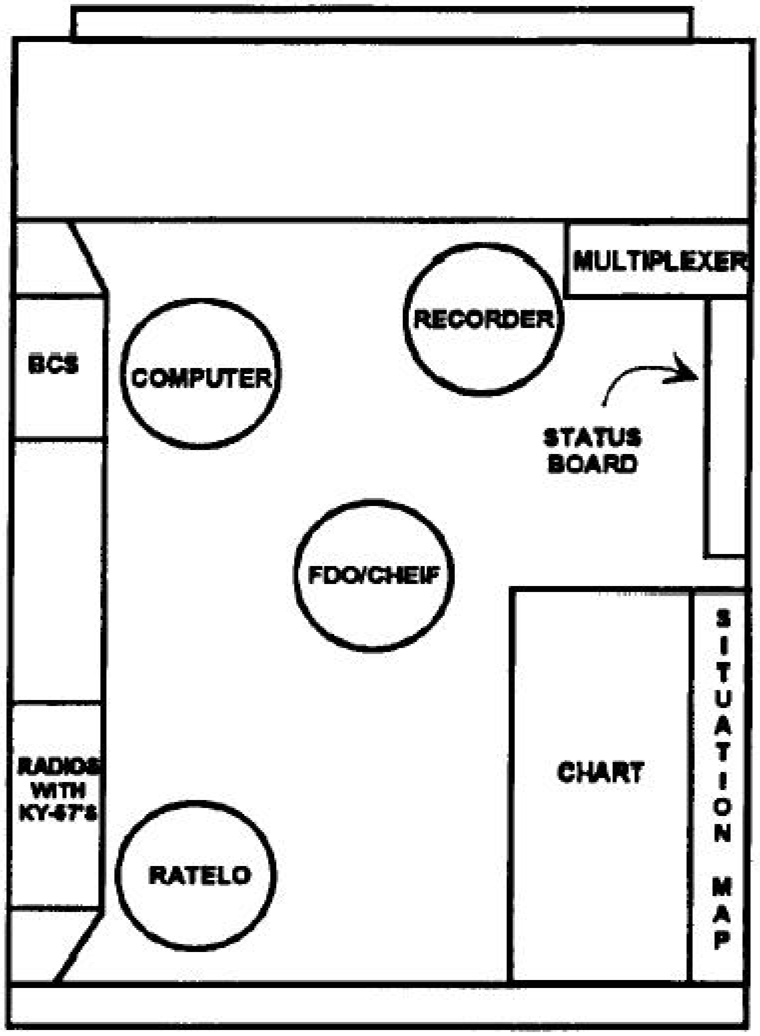


Figure 2. Internal Top View of Battery FDC (From: FM 6-40)

The FDC is the control center, or brains, of the gunnery team. The FDC personnel receive calls for fire from observers and convert the request, using the special equipment (manual or automatic), into firing data. The firing data are then sent to the howitzer sections as fire commands. This procedure is called technical fire direction. If the battery is operating autonomously then the FDC can also conduct tactical fire direction, which in general means to accept or reject the requested calls for fire.

2. FDC Procedures

The FDC has many responsibilities. This thesis only focuses on the procedures that concern the completion of a fire mission, and especially those missions that are requested from the forward observers.

When the forward observer requests a call for fire, a communication process begins between the forward observer and the radio/telephone operator of the FDC. The forward observer provides, with a number of separate messages, the elements of his call for fire (observer identification, target location, description, and method of engagement). Then, the Fire Direction Officer (FDO) decides if the target will be hit or not and informs the observer with a specific message which is called the Message to Observer (MTO). The personnel of the FDC makes the necessary gunnery computations to convert that target location data into firing data which are given to the battery as a Fire Command. When the battery is ready, a round is fired and the observer is informed by the FDC for the firing. The observer watches the explosion to see if the target has been hit. If the observer is not satisfied with the result, the latter can request subsequent corrections. When considering the fire successful, the Fire for Effect (FFE) is requested in which all the cannons fire at the target to succeed the desirable effect. After the FFE, the observer can request repetition when desiring that the target be hit more or requests End of Mission (EOM).

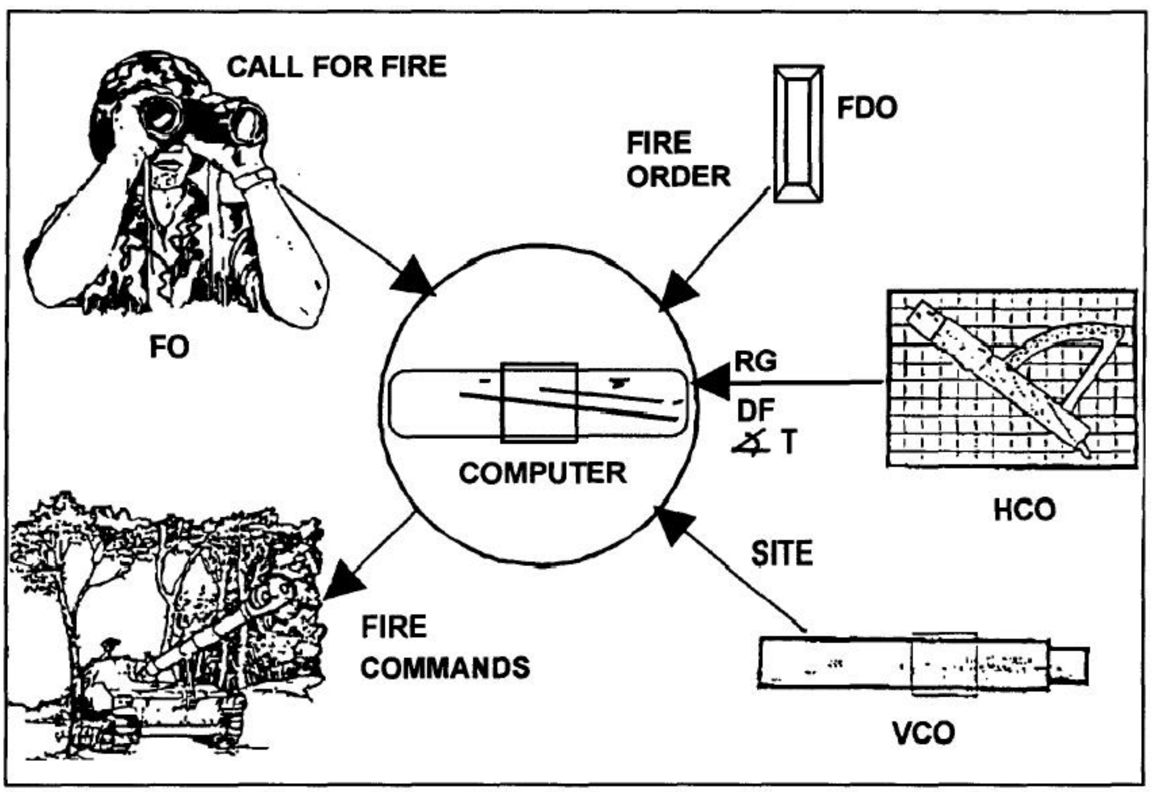
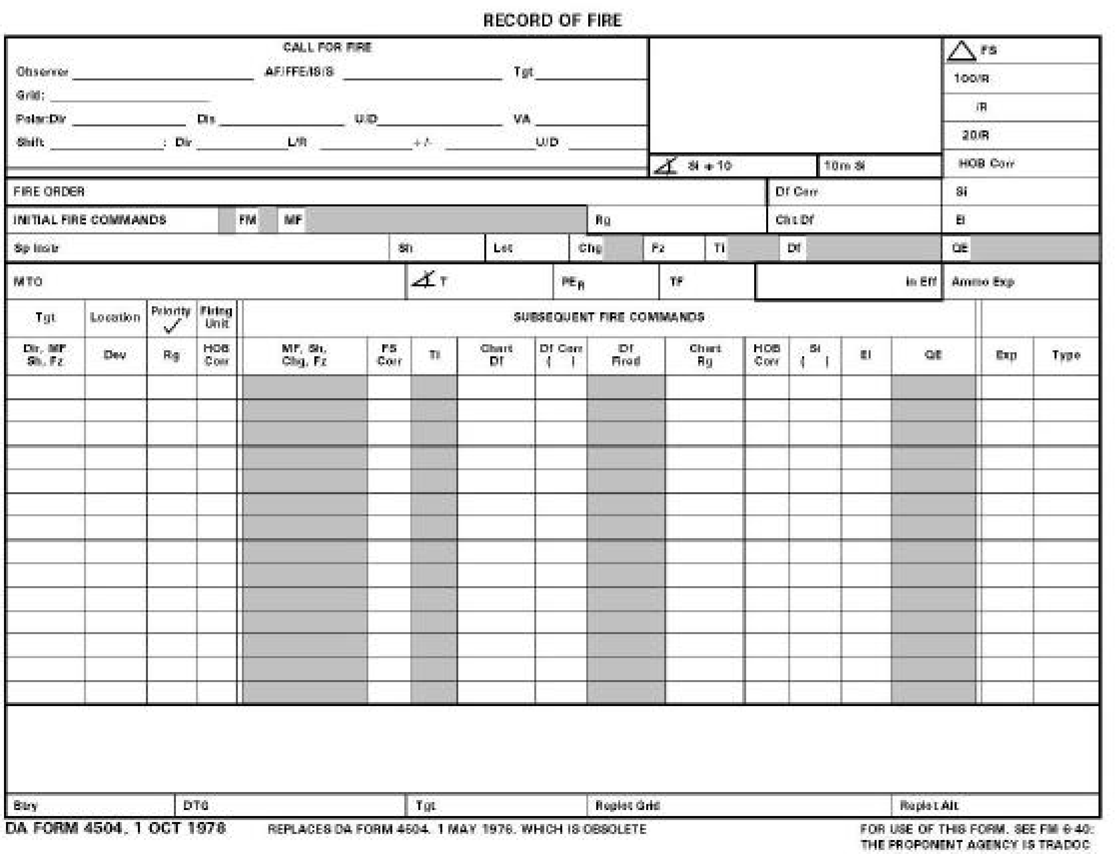


Figure 3. Flow of Information Between the Gunnery Team (From: FM 6-40)

During the firing process, data are recorded in the Form DA 4504, as shown in Figure 4.

Form 4504 (Record of Fire) is a legal document used for determining and recording firing data. It is organized to allow a smooth flow in determining and processing a fire mission. It is used for the following:

- Record the call for fire.
- Compute and record firing data for all types of fire missions.
- Keeping a permanent record of a fire mission, to include the type and amount of ammunitions expended during the mission.



RECORD OF FIRE

CALL FOR FIRE

Observer ______ AF/FFE/IS/S ______ Tgt ______

Grid: ______

Polar:Dir ______ Dis ______ U/D ______ VA ______

Shift ______ : Dir ______ L/R ______ +/- ______ U/D ______

∡ Si + 10 | 10m Si

△ FS | 100/R | /R | 20/R | HOB Corr | Si | El | QE | Ammo Exp

FIRE ORDER | Df Corr

INITIAL FIRE COMMANDS | FM | MF | Rg | Cht Df

Sp Instr | Sh | Lot | Chg | Fz | Ti | Df

MTO | ∡ T | PE_R | TF | In Eff

Tgt	Location	Priority ✓	Firing Unit	SUBSEQUENT FIRE COMMANDS												
Dir, MF Sh, Fz	Dev	Rg	HOB Corr	MF, Sh, Chg, Fz	FS Corr	Ti	Chart Df	Df Corr ( )	Df Fired	Chart Rg	HOB Corr	Si ( )	El	QE	Exp	Type

Btry | DTG | Tgt | Replot Grid | Replot Alt

DA FORM 4504, 1 OCT 1978 REPLACES DA FORM 4504, 1 MAY 1976, WHICH IS OBSOLETE

FOR USE OF THIS FORM, SEE FM 6-40; THE PROPONENT AGENCY IS TRADOC

Figure 4. Record of Fire - DA Form 4504 (From: FM 6-40)

3. FDC Equipment

Some of the FDC equipment used in a call for fire are the following.

- Firing Chart

The FDC uses a firing chart. A firing chart is a map, photomap, grid sheet, or sheet of plain paper on which are shown the relative positions of firing batteries, registration points, targets, and other details needed to determine firing data. The purpose of a firing chart is to determine the range and direction from the guns to the target.

- Firing Tables

- Measurements Tools

C. ELEMENTS OF THE CALL FOR FIRE

1. Description

A call for fire (CFF) is a message prepared by the observer. It contains all information needed by the FDC to determine the method of a target attack. It is a request for fire, not an order. It must be sent quickly but clearly enough that it can be understood, recorded, and read back, without error, by the FDC recorder. The observer should tell the Radio – Telephone Operator (RATELO) that he has seen a target so the RATELO can start the call for fire while the target location is being determined. Information is sent as it is determined rather than waiting until a complete call for fire has been prepared.

Regardless of the method of target location used, the normal call for fire is sent in three parts consisting of six elements. The six elements, in the sequence in which they are transmitted, are the following:

- Observer identification.
- Warning order.
- Target location.
- Target description.
- Method of engagement.
- Method of fire and control.

The three transmissions in a call for fire are as follows:

- Observer identification and warning order.
- Target location.
- Description of target, method of engagement, and method of fire and control.

There is a break after each transmission, and the FDC reads back the data.

2. Observer Identification

This element of the call for fire tells the FDC who is calling for fire.

3. Warning Order

The warning order tells the FDC the type of mission and the type of target location that will be used. The warning order consists of the type of mission, the size of the element to fire for effect, and the method of target location. It is a request for fire unless prior authority has been given to order fire.

a. Type of Mission

(1) Adjust Fire. When the observer believes that an adjustment must be made, because of questionable target location or lack of registration corrections, he announces ADJUST FIRE.

(2) Fire for Effect. The observer should always strive for first-round FFE. The accuracy required to fire for effect depends on the accuracy of target location and the ammunition being used. When the observer is certain that the target location is accurate and that the first volley should have the desired effect on the target so that little or no adjustment is required, he announces FIRE FOR EFFECT.

(3) Suppression. To quickly bring fire on a target that is not active, the observer announces SUPPRESS, followed by the target identification. Suppression (S) missions are normally fired on preplanned targets, and the duration is specified in the call for fire.

(4) Immediate Suppression and Immediate Smoke. When engaging a planned target or target of opportunity that has taken friendly maneuver or aerial elements under fire, the observer announces IMMEDIATE SUPPRESSION or IMMEDIATE SMOKE, followed by the target location. Though the grid method of target location is the most common, any method of target location may be used in firing an immediate suppression or immediate smoke mission.

b. Size of Element to Fire for Effect

The observer may request the size of the unit to fire for effect; for example, BATTALION. Usually, this is done by announcing the last letter in the battalion FDC’s call sign. For example, T6H24 is announced H. The observer should

never refer to a battery or other unit in the clear. He should refer to it by call sign. If the observer says nothing about the size of the element to fire, the battalion FDC makes that decision.

c. Method of Target Location

(1) Polar Plot. If the target is located by the polar plot method of target location, the observer announces POLAR; for example, ADJUST FIRE, POLAR, OVER.

(2) Shift from a Known Point. If the target is located by the shift from a known point method of target location, the observer announces SHIFT, followed by the known point; for example, ADJUST FIRE, SHIFT KNOWN POINT 1, OVER.

(3) Grid. If the grid method of target location is being used, the word grid is not announced; for example, ADJUST FIRE, OVER.

4. Target Location

This element enables the FDC to plot the location of the target to determine firing data.

a. Grid Mission

In a grid mission, six-place grids normally are sent. Eight-place grids should be sent for registration points or other points for which greater accuracy is required. The Observer – Target (OT) direction normally will be sent after the entire initial call for fire, since it is not needed by the FDC to locate the target.

b. Shift Mission

In a shift from a known point mission, the point or target from which the shift will be made is sent in the warning order. The point must be known to both the observer and the FDC. The observer then sends the OT direction. Normally, it is sent in mils. However, the FDC can accept degrees or cardinal directions, whichever is specified by the observer. The corrections are sent next. The lateral shift is how far left or right the target is from the known point. The range shift is how much farther [ADD] or closer [DROP] the target is in relation to the known point, to the nearest 100 meters. The vertical shift is how much the target is above [UP] or below [DOWN] the altitude of the known point, to the nearest 5 meters.

c. Polar Mission

In a polar plot mission, the word polar is specified in the warning order. The observer's location must be known to the FDC. The observer then sends the direction and distance. A vertical shift tells the FDC how far, in meters, the target is located above or below the observer's location. Vertical shift may also be described by a vertical angle (VA), in mils, relative to the observer's location.

5. Target Description

The observer must describe the target in enough detail so that the FDC can determine the amount and type of ammunition to use. The FDC selects different ammunition for different types of targets. The observer should be brief but accurate. The description should contain the following:

- What the target is (troops, equipment, supply dump, trucks, and so forth).
- What the target is doing (digging in, in an assembly area, and so forth).
- The degree of protection (in open, in foxholes, in bunkers with overhead protection, and so forth).

The target size and shape if these are significant. If the target is rectangular, the length and width (in meters) and the attitude (azimuth of the long axis 0000-3199) to the nearest 100 mils should be given; for example, 400 BY 200, ATTITUDE 2800. If the target is circular, the radius should be given; for example, RADIUS 200. Linear targets may be described by length, width, and attitude.

6. Method of Engagement

The observer may indicate how he wants to attack the target. This element consists of the type of adjustment, trajectory, ammunition, and distribution. DANGER CLOSE and MARK are included as appropriate.

a. Type of Adjustment

Two types of adjustment may be employed—precision and area. Unless precision fire is specified, area fire will be used.

(1) Precision Fire. Precision fire is conducted with one weapon on a point target. It is used either to obtain registration corrections or to destroy a target. When the mission is a registration, it is initiated by the FDC with a message to the observer. If the target is to be destroyed, the observer announces DESTRUCTION.

(2) Area Fire. Area fire is used to attack an area target. Since many area targets are mobile, the adjustment should be as quickly as possible, consistent with accuracy, to keep the target from escaping. A well-defined point at or near the center of the area to be attacked should be selected and used as an aiming point. This point is called the adjusting point during adjust fire missions. To achieve surprise, fire may be adjusted on an auxiliary adjusting point and, after adjustment is completed, the fire for effect shifted to the target. Normally, an adjustment on an area target is conducted with one adjusting weapon.

b. Danger Close

DANGER CLOSE is included in the method of engagement when the target is (rounds will impact) within 600 meters of friendly troops for mortar and artillery, 750 meters for naval guns 5-inches and smaller, and 1,000 meters for naval guns larger than 5-inches. For naval 16-inches ICM, danger close is 2,000 meters.

c. Mark

MARK is included in the method of engagement to indicate that the observer is going to call for rounds for either of the following reasons:

- To orient himself in his zone of observation.
- To indicate targets to ground troops, aircraft, or fire support.

d. Trajectory

Low-angle fire is standard for field artillery. If high-angle fire is desired, it is requested immediately after the type of engagement. If high angle is not specified, low angle will (normally) be used. If the firing unit determines that high angle must be used to attack a target, the unit must inform the observer that high angle will be used. Mortars fire only high angle.

e. Ammunition

The observer may request any type of ammunition during the adjustment or the FFE phase of his mission. Shell HE with fuse quick is normally used in adjustment. If that is what the observer desires, it does not need to be requested in the call for fire. If the observer does not request a shell-fuse in effect, the fire direction officer (FDO) determines the shell-fuse combination.

(1) Projectile. Examples of requests for other than HE projectile are ILLUMINATION, ICM, and SMOKE.

(2) Fuse. Most missions are fired with fuse quick during the adjustment phase. If quick fuse is desired, fuse is not indicated. Illuminating, ICM, and smoke projectiles are fused with time fuses. Therefore, when the observer requests ILLUMINATION, ICM, or SMOKE, TIME is not announced.

(3) Volume of Fire. The observer may request the number of rounds to be fired by the weapons firing in effect. For example, 3 ROUNDS indicates that the firing unit will fire three volleys.

f. Distribution

The observer may control the pattern of bursts in the target area. This pattern of bursts is called a sheaf. Unless otherwise requested, the FDC assumes a circular target with a 100-meter radius. A converged sheaf places all rounds on a specific point and is used for small, hard targets. Special sheaves of any length and width may be requested. An open sheaf separates the bursts by the maximum effective burst width of the shell fired. If target length and width are given, attitude also must be given.

7. Method of Fire and Control

The method of fire and control element indicates the desired manner of attacking the target, whether the observer wants to control the time of delivery of fire, and whether he can observe the target. Methods of control at my command (AMC) and time on target (TOT) are especially useful in massing fires. The AMC and TOT missions achieve surprise and maximize the effects of the initial volley on a target. Methods of fire and control are announced by the observer with the terms discussed below.

a. Method of Fire

In area fire, the adjustment normally is conducted with one howitzer or with the center gun of a mortar platoon or section. If for any reason the observer determines that PLATOON RIGHT (LEFT) will be more appropriate, he may request it. Adjusting at extreme to a unit distance may be easier with two guns firing. The normal interval of time between rounds fired by a platoon or battery right (left) is 5 seconds. If the observer wants some other interval, he may so specify.

b. Method of Control

(1) At My Command. If the observer wishes to control the time of delivery of fire, he includes AT MY COMMAND in the method of control. When the pieces are ready to fire, the FDC announces PLATOON (or BATTERY or BATTALION) IS READY, OVER. Call signs are used. The observer announces FIRE when he is ready for the pieces to fire. AT MY COMMAND remains in effect throughout the mission until the observer announces CANCEL AT MY COMMAND, OVER.

(2) Cannot Observe. CANNOT OBSERVE indicates that the observer cannot see the target because of vegetation, terrain, weather, or smoke. However, he has reason to believe that a target exists at the given location and that it is important enough to justify firing on it without adjustment.

(3) Time on Target. The observer may tell the FDC when he wants the rounds to impact by requesting TIME ON TARGET (so many) MINUTES FROM...NOW, OVER or TIME ON TARGET 0859, OVER.

(4) Continuous Illumination. If no interval is given by the observer, the FDC determines the interval by the burning time of the illuminating ammunition in use. If any other interval is required, it is indicated in seconds.

(5) Coordinated Illumination. The observer may order the interval between illuminating and HE shells, in seconds, to achieve a time of impact of the HE coincident with optimum illumination; or he may use normal AT MY COMMAND procedures.

(6) Cease Loading. The command CEASE LOADING is used during firing of two or more rounds to indicate the suspension of loading rounds into the gun(s). The gun sections may fire any rounds that have already been loaded.

(7) Check Firing. CHECK FIRING is used to cause an immediate halt in firing.

(8) Continuous Fire. In field artillery, mortars, and naval gunfire, continuous fire means loading and firing as rapidly as possible, consistent with accuracy, within the prescribed rate of fire for the equipment. Firing will continue until suspended by the command CEASE LOADING or CHECK FIRING.

(9) Repeat. REPEAT can be given during adjustment or FFE missions.

(a) During Adjustment. REPEAT means fire another round(s) with the last data and adjust for any change in ammunition if necessary. REPEAT is not sent in the initial call for fire.

(b) During Fire for Effect. REPEAT means fire the same number of rounds using the same method of fire for effect as last fired. Changes in the number of guns, the previous corrections, the interval, or the ammunition may be requested.

(10) Followed By. This is part of a term used to indicate a change in the rate of fire, in the type of ammunition, or in another order for fire for effect; for example, WP FOLLOWED BY HE.

8. Corrections of Errors

Errors are sometimes made in transmitting data or by the FDC personnel in reading back the data. If the observer realizes that a mistake has been made in his transmission or that the FDC has made an error in the read back, he announces CORRECTION and transmits the correct data.

EXAMPLE

The observer transmitted SHIFT KNOWN POINT 2, OVER, DIRECTION 4680. He immediately realizes that he should have sent DIRECTION 5680. He announces CORRECTION, DIRECTION 5680, after receiving the correct read back, and he may continue to send the rest of the call for fire. When an error has been made in a sub-element and the correction of that sub-element will affect other transmitted data, CORRECTION is announced. Then the correct sub-element and all affected data are transmitted in the proper sequence.

EXAMPLE

The observer transmitted LEFT 200, ADD 400, UP 40, OVER. He then realizes that he should have sent DROP 400, to correct this element, he sends CORRECTION

LEFT 200, DROP 400, UP 40, OVER. The observer must read back the entire sub-element, because the LEFT 200 and UP 40 will be canceled if they are not included in the corrected transmission.

9. Message to Observer

After the FDC receives the call for fire, the FDO analyzes the target. If the target is to be attacked, the FDO issues the fire order as his decision on how the target will be attacked. The observer is informed of this decision through the message to observer.

The message to the observer consists of four elements and is composed by the RATELO.

a. Units to Fire

The first element is the unit(s) that will fire the mission. It is always announced. If a battalion is firing in effect with one battery or platoon adjusting, the MTO will designate the FFE unit (battalion) and the adjusting unit (battery or platoon). The units to fire are identified by their radio call signs, using long call signs, short call signs, or the first letter of the short call sign.

b. Changes or Additions to the Call for Fire

The second element of the MTO allows the FDC to inform the observer of changes and/or additions made by the FDO to the call for fire. If high-angle fire is to be used, HIGH ANGLE must be included in the MTO if the observer did not request it. The following examples use the previously stated call signs.

c. Number of Rounds

The third element is the number of volleys in fire for effect. The number of rounds to be fired in effect is always announced.

d. Target Number

The last element is the target number assigned to the mission for reference purposes, and it is always announced. This is done to avoid confusion if multiple missions are being fired or if more than one observer is operating on the radio net. Target numbers are used in sequential order based on the units target block.

10. Additional Information

The following additional information may be announced with or after the message to the observer.

a. Probable Error in Range

If the probable error in range for an area fire mission is equal to or greater than 38 meters, the FDC will inform the observer. For precision fire, the FDC will inform the observer if the probable error in range is equal to or greater than 25 meters. The actual value is not announced. For example, the RATELO would announce PROBABLE ERROR IN RANGE GREATER THAN 38 METERS.

b. Angle T

Angle T is sent to the observer when it is equal to or greater than 500 mils or if the observer requests it. It is announced to the nearest 100 mils. For example, if angle T is 580 mils, it is expressed and announced as ANGLE T 600.

c. Pulse Repetition Frequency Code

The pulse repetition frequency (PRF) code for a Copperhead mission is transmitted in voice operations; for example, the RATELO will announce PRF CODE 241. The range and direction of approach, left or right of the observer-target line, are needed to orient the footprint.

d. Time of Flight

Time of flight (TOF) is announced to the nearest whole second. It is announced to observers when targets are engaged with Copperhead, when moving targets are engaged, when conducting high-angle missions, when using an aerial observer, or when requested by the observer. For example, the RATELO would announce TIME OF FLIGHT 34 SECONDS.

e. Splash

Splash informs the observer that the round(s) fired will impact in five seconds. It must be sent to aerial observers and during high-angle fire missions. It can also be sent at the observer’s request.

f. Shot and Rounds Complete

SHOT is announced to the observer to report when a round has been fired. Rounds complete is announced to the observer when all rounds for a particular mission have been fired. During an adjust-fire mission, SHOT is announced after each round. Once the FFE phase is initiated, SHOT is announced only on the initial round. Once all

rounds have been fired, rounds complete is announced to the observer. For an FFE mission, SHOT is announced only on the initial round. Once all rounds have been fired, rounds complete is announced to the observer.

11. Authentication

When non-secure communications are used and excluding unique fire support operations such as suppressive fires posture, challenge and reply authentication is considered a normal element of initial requests for indirect fire. The FDC challenges the FO after the last read back of the fire request. The FO transmits the correct authentication reply to the FDC immediately following the challenge. Authentication replies exceeding 20 seconds are automatically suspect and a basis for re-challenge. Subsequent adjustment of fire or immediate engagement of additional targets by the FO originating the initial fire request normally would not require continued challenge by the FDC.

Two methods of authentication are authorized for use: challenge and reply, and transmission which is commonly referred to as self-authentication. The operational distinction between the two is that challenge and reply requires two-way communications, whereas transmission authentication does not. Challenge and reply authentication will be used whenever possible. Transmission authentication will be used if authentication is required and it is not possible or desirable for the receiving station to reply; for example, imposed radio silence, final protective fire, and immediate suppression.

EXAMPLES

Transmission authentication for final protective fire would be FIRE THE FPF. AUTHENTICATION IS WHISKEY HOTEL, OVER. Transmission authentication for immediate suppression would be T23 THIS IS T44, IMMEDIATE SUPPRESSION, GRID NK124321, AUTHENTICATION IS TANGO UNIFORM, OVER.

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III. SYSTEM REQUIREMENTS

A. INTRODUCTION

The FDC application is not a stand-alone application. It works together with the FOPCSIM application creating a peer-to-peer network session for communication.

The FDC works as a server (host) while FOPCSIM acts as a client. There can be up to three clients (Forward Observers) connected to one server (FDC). This organization comes from the typical artillery battery organization, in which each battery has one FDC and three Forward Observers.

Although FDC is not a stand-alone application, it can operate like one with some limited functionality. This functionality contains the following.

- Navigate through the loaded map.
- Load a map from another area.
- Load a previously completed and saved mission. The user can view and examine the filled DA 4054 form as well as the messages that have been exchanged during this mission between the FDC and the observer.

B. USER REQUIREMENTS

The user of the FDC application must have the following skills.

1. Computer Knowledge

Some experience on using desktop application in windows-based systems is required, which includes the use of a mouse (move sliders, click on buttons, select a menu item etc.) and a keyboard (input, delete and modify text in text fields). The concept of open files in an application, how to exit the application, how to handle dialog boxes etc, must also be understood.

A basic knowledge of how networks work from the user perspective is also required. More specifically, the user must be aware that if the server (host) is not up and running, the client cannot be connected to it. Of course, the system will inform him after a specific timeout that the connection is not possible. He also must know that connections are not possible if the PC's that run the programs are not connected to a network (LAN, WAN, Wireless, peer-to-peer etc.).

2. Military Skills

The FDC application, as well as the FOPCSIM application, is oriented towards military personnel, and especially those who have specialized in artillery procedures. The user must have knowledge of artillery concepts and must understand the purpose of the FDC and the forward observer. Although military personnel are training to perform observed fire independent of their specialty in order to be able to use the FOPCSIM application, the procedures in the FDC are known only to artillery personnel. Thus, it is better if the user of the FDC application has an artillery background in order to understand the functionality and some special terminology used in FDC. For example, MTO is Message to Observer, OP is Observer Post, etc.

C. HARDWARE

The FDC application does not require much computer power. It is a light desktop application and works well on a medium modern PC. The proposed requirements follow although they are not strictly enforced.

1. Minimum System Requirements

- Windows 98, NT, 2000 or XP operating system
- Pentium II 266 MHz processor
- 64 MB RAM
- 20 MB of free hard disk space
- DirectX / OpenGL capable graphics card with 16 MB of memory.
- Network Interface (Card)

2. Recommended System Requirements

- Windows 98, NT, 2000 or XP operating system
- Pentium III 500 MHz processor
- 128 MB RAM
- 20 MB of free hard disk space
- DirectX / OpenGL capable graphics card with 32 MB of memory.
- Network Interface (Card)

D. SOFTWARE

The following list is the required software for the FC application to work correctly:

- Microsoft Windows 98, ME, NT, 2000 or XP operating system.
- DirectX 8.1 runtime library. DirectX 8.1 is already included with Microsoft Windows XP. In Windows 98, Windows 98 SE, Windows Me, or Windows 2000, it must be downloaded and installed.
- Graphics Framework Library (gfLIB).
- Vega Runtime License (for the FOPCSIM application)

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IV. SYSTEM DESCRIPTION

A. INTRODUCTION

The FDC application is a desktop application for a PC that simulates the procedures of an artillery battery FDC during a fire mission. It works together with the FOPCSIM application. The two systems are connected in a network using a peer-to-peer connection and exchanging messages for the completion of a call for fire that the forward observer has requested. The entire system constitutes a more realistic training system for the forward observer of the artillery.

The FDC application is a windows application. The main window is a tabbed window consisting of four panels. The first one represents a map from the area where the mission takes place. The other three panels represent the DA 4054 form, one for each observer, which is completed step by step during a fire mission process.

The rightmost panel of the application consists of three areas in which there are some text fields for viewing exchanged messages as well as some pushbuttons for controlling the flow of the messages.

B. SYSTEM DEVELOPMENT

1. User Interface

The user interface has been created using the Fast Light Tool Kit ("FLTK") version 1.1.3. FLTK is a C++ Graphical User Interface ("GUI") toolkit for UNIX, Microsoft Windows and MacOS. The FLTK library and included programs are provided under the terms of the GNU Library General Public License (LGPL).

The FLTK User Interface Designer (FLUID) was used for the creation of the main window with its contents. This is a tool for creating a user interface graphically. The toolkit generates source files for C++, which are compiled with the other files of the project creating the executable. In our case, Microsoft Visual C++ compiler was used.

a. Map View

The Map View is a widget which has as a background a bitmap with the map of a specific area. The user can load another map if it is available. Some restrictions

apply in the format of the map. It currently supports bmp and gif formats, as well as the recognition of the area that the map represents. There must be another text file which has some information for the map (base coordinates, pixel resolution etc.).

Some drawings take place on the map that represent various elements that are useful to the FDC such as firing batteries, registration points, targets, and other details.

b. Form View

The Form View is a widget which has a bitmap of the DA form 4052 as a background which is the main form that the FDC personnel use to record a fire mission. This form is completed during each call for fire and consists of information concerning the observer and his messages to the FDC, various manual gunnery computations, fire orders to the battery cannons and other information such as ammunition consumption, date/time of fire mission, target recording information. Since the scope of the application is to deal with the communication with the forward observer, only the information to which it is related will be completed.

c. Other Widgets

The right panel has three sub-panels, one for each observer. In each sub-panel, there are two text fields. One is for recording all the messages between the FDC and the forward observer and the other for presenting the outgoing message of the FDC. Usually this message is a read-back to the observer's message. This message is sent back to the observer that has sent it by pressing the reply button. There are two other buttons, initially hidden, that become visible when it is time for them to function. The [SentMTO] button, when pressed, displays the MTO dialog which contains the information of the message to the observer. After the user modifies the information and presses the Submit button, the MTO message is sent to the observer. The [Shoot] button sends a shoot message to the observer.

2. Network

For the networking part of our system, the Graphics Framework Library (gfLib) was used. This is a high-level API used in graphical 3D applications. It is built upon a handful of other well-developed libraries and encapsulates their functionalities. It supports most Win32 platforms and uses OpenGL as a renderer. The networking

functionality of gfLib is used which is the gfNetwork module. It is based on DirectX 8.1. This module creates a peer-to-peer network session using DirectPlay. In this implementation, one node hosts the session in which a number of clients can be connected to create the entire network. Each one node can send messages to all other nodes that are connected to the session. However, in our case, we do not want the system to work in this manner. Thus, we made some modifications in order for the message to go to a specific recipient. For example, the messages from one observer are delivered only to the FDC. There is no need or usefulness for it to be delivered to another observer.

C. HOW THE SYSTEM WORKS

By starting the FDC application, the user interface is loaded and the network session is established and becomes ready to accept connections from FOPCSIM clients. Initially, the three observers are disconnected. When an observer (a FOPCSIM user) starts his application, some options appear on the introductory setup screen, as show in Figure 5. As concerns the FDC options, if he selects the training, he is working as a stand-alone. If he checks the realistic option, then the program tries to connect to the already open FDC session. If the FDC (host) is not up and running, then the FOPCSIM user is informed after a specific amount of time (default timeout) that the connection is not possible.

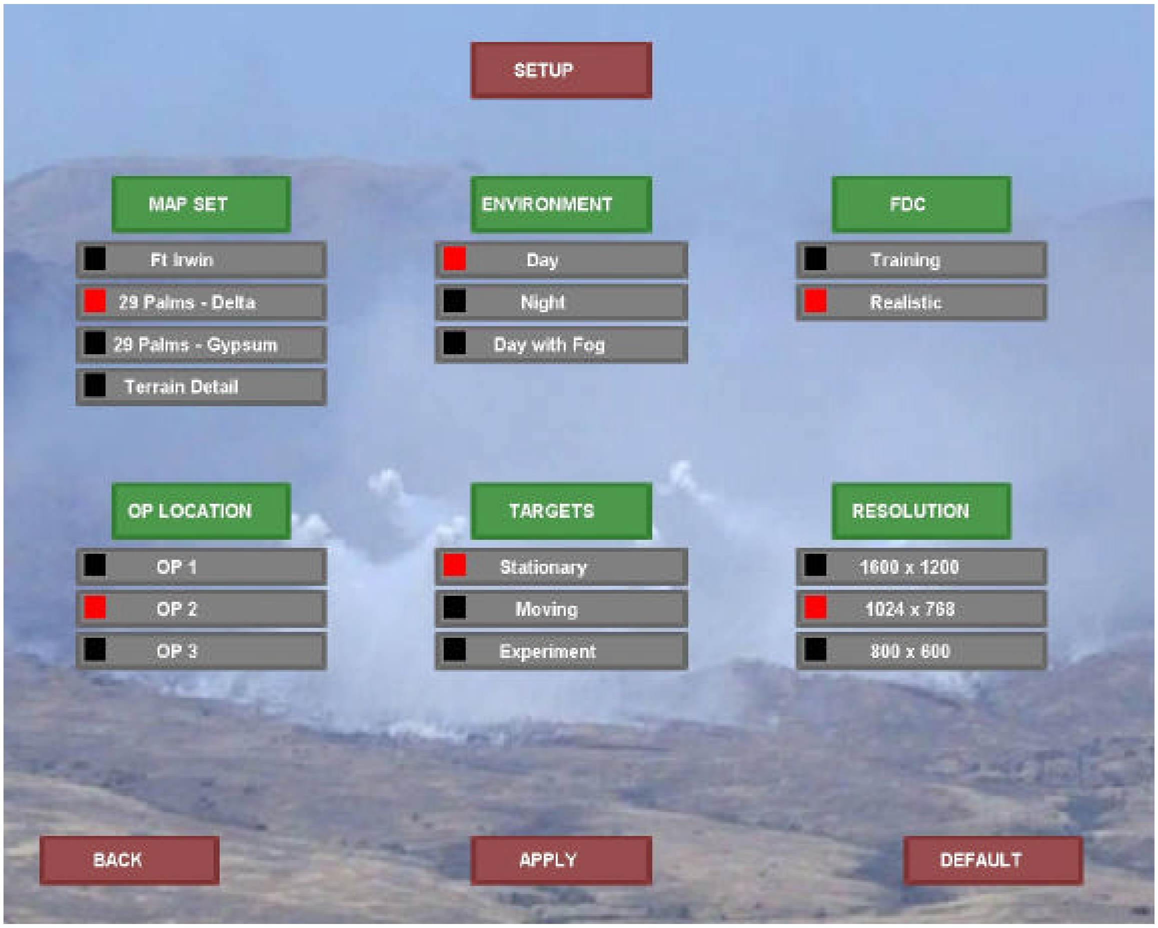

Figure 5. FOPCSIM Setup Screen

In the case of a successful connection, the respective panel of the FDC program shows that this observer is connected, he has provided his identification, and he is ready to request a fire mission. The FDC user replies to this request.

1. Call for Fire (CFF) Scenario

The call for fire consists of a succession of messages between the observer and the FDC. Regardless of the method of target location used, the normal call for fire is sent in three transmissions consisting of six elements as follows:

- 1st Transmission: Observer Identification/Warning Order
- 2nd transmission: Target Location
- 3rd Transmission: Target Description/Method of Engagement/Method of Fire and Control.

Then, if necessary, subsequent transmissions can follow which are for changes/corrections or to end the mission. The mission is finished when the observer will send the last transmission which is an End of Mission (EOM). For consistency with the FOPCSIM, the first transmission is sent in two separate messages.

a. Observer Identification

It is sent only once when the observer is connected to the FDC. In subsequent fire missions it is omitted.

EXAMPLE

FO: G4H this is H30, radio check, over.

FDC: H30 this is G4H, ready for fire mission, out (see figure).

Figure 6. FO Identification Transmission

b. Warning Order

In this transmission, the observer specifies the type of mission, size of element to fire, and method of target location.

EXAMPLE

FO: Adjust Fire Polar, over.

FDC: Adjust Fire Polar, out (see figure).

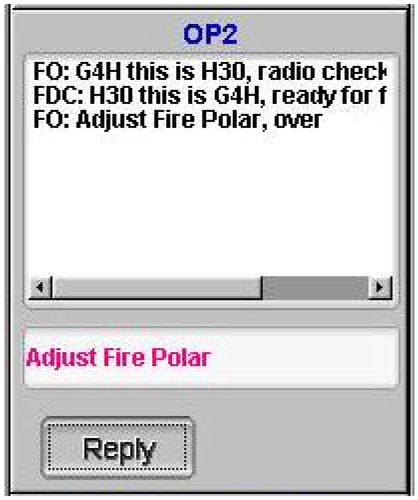

Figure 7. FO Warning Order

c. Target Location

The observer sends the target location accordingly with the method that he has specified in the warning order transmission.

(1) Grid Coordinates. In this case, he sends the grid location of the target, usually six digits, three for each coordinate.

(2) Polar Coordinates. The observer sends the direction and distance. A vertical shift tells the FDC how far, in meters, the target is located above or below the observer's location.

(3) Shift from Known Point. In a shift from a known point mission, the point or target from which the shift will be made is sent in the warning order. The point must be known to both the observer and the FDC. Next, he sends the target direction, the lateral shift (how far left or right the target is from the known point), the range shift (how much farther [ADD] or closer [DROP] the target is in relation to the known point), and the vertical shift (how far the target is above [UP] or below [DOWN] the altitude of the known point).

EXAMPLE

FO: Direction 6300 Distance 1500 Up 10, over.

FDC: Direction 6300 Distance 1500 Up 10, out.

Figure 8. FO Target Location

When the FDC receives the target location, then the target is plotted in the map. The target is represented as a cross with a pin attached in its center. The purpose of the pin is to be "moved" when the observer will give subsequent correction in order to represent the new (corrected) target location, as demonstrated in Figure 9.

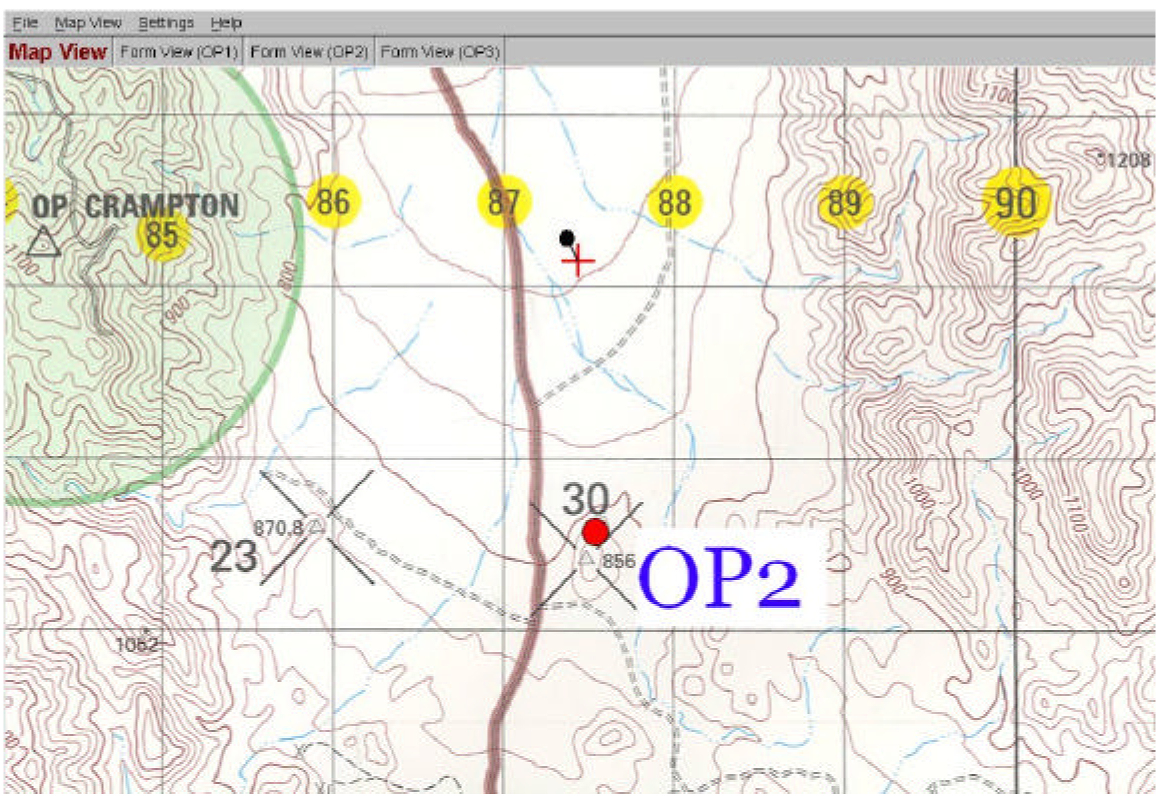

Figure 9. Target Representation on the Map

d. Target Description/Method of Engagement/Method of Fire and Control

(1) Target Description. What the target is, what it is doing, number of elements, degree of protection, and target shape if significant.

(2) Method of Engagement. The observer may indicate how he wants to attack the target. This element consists of the type of adjustment, trajectory, ammunition, and distribution.

(3) Method of Fire and Control. The method of fire and control element indicates the desired manner of attacking the target, whether the observer wants to control the time of delivery of fire, and whether he can observe the target.

EXAMPLE

FO: BTR-70 in open, Quick in Effect, over.

FDC: BTR-70 in open, Quick in Effect, out.

Figure 10. Target Description / Engagement Method / Fire Control

e. Message to Observer (MTO)

After the FDC receives the call for fire, the FDO determines how the target will be attacked. That decision is announced to the observer in the form of a message to observer (MTO). The MTO consists of the following four items.

(1) Unit(s) to Fire. The battery (or batteries) that will fire the mission is (are) announced.

(2) Changes to the Call for Fire. Any change to what the observer requested in the call for fire is announced.

(3) Number of Rounds. The number of rounds per cannon in fire for effect is announced.

(4) Target Number. A target number is assigned to each mission to facilitate processing of subsequent corrections.

In the FDC application when the user replies to the 3rd transmission, the [SendMTO] button becomes visible. When the user clicks on it, the MTO dialog appears, as seen in Figure 12, with the four items completed with values taken from the current call for fire information. The user can change these values as desired and then transmit the message.

Figure 11. FDC Send MTO

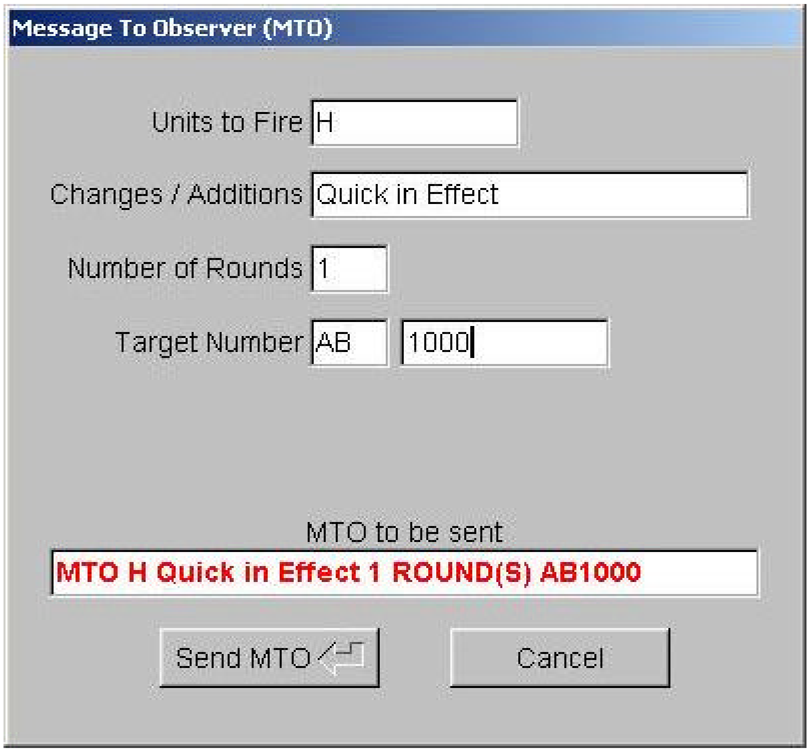

Figure 12. MTO Dialog

When the user presses the [SendMTO] button, the composed message will be sent to the specific observer. The observer receives this message and replies back pressing the 'o' (out) button in the FOPCSIM application.

EXAMPLE

FDC: MTO H 1 ROUND(S) AB1000, over

FO: MTO H 1 ROUND(S) AB1000, out.

f. Shoot Message

By pressing the [Shoot] button (see figure) the FDC sends a shoot message to the FOPCSIM application. This message contains the location of the impact and the time of flight of the projectile. Before the shoot message is transmitted, some computations happen in order to determine the location of impact. These computations are described later in the ballistic model of the application.

Figure 13. FDC Shoot Message

When the FOPCSIM receives this message and when the time of flight expires, the explosion on the ground occurs.

2. Calculation of the Location of Impact (Ballistic Model)

a. Introduction

The location of the target is given by the FOPCSIM user using one of the methods discussed previously. In the FOPCSIM application, this is also the location of the impact. This is not realistic because in real situations, many factors affect the trajectory of the projectile and result in a different location of impact.

These factors are studied in the science of ballistics. FDC application uses some of these concepts, and using a simple ballistic model affects the precision and accuracy of the firing data. The result is a different location of impact especially in the first round of fire, so the observer tries to overcome these factors by providing corrections on the first impact and trying to have the explosion occur in the target area.

This ballistic model is simple and, most of the time, creates random variations on the firing data, because its purpose is not to describe the real conditions that affect the motion of the projectile, as this is not the scope of the thesis, but to introduce this situation in the training of the observer with our system. For example, the wind direction and speed affect the projectile during its flight towards the target in a different way based on different types of projectiles. In our model, the wind will affect all types of projectiles the same using a simple function to calculate the size of the affection.

A summary of the theory of ballistics based on FM 6-40 appears in Appendix B.

b. Description

In the ballistic model, the following factors are used to determine the affected location of the impact.

(1) Muzzle Velocity.[2] This is the velocity of the projectile just when it leaves the muzzle of the tube. Firing tables give the standard muzzle velocity per projectile, propellant and tube type. Our model randomly changes the standard muzzle velocity in a range of -5 m/s to 5 m/s.

(2) Propellant Temperature. The standard muzzle velocity has been measured using propellant at the temperature of 70° F. Any difference from this temperature impacts the muzzle velocity based on the type of projectile and the type of propellant. In our model, a random propellant temperature is determined in the range of 40 to 100° F. Then, the difference of the standard temperature determines the difference of the muzzle velocity by a factor of 0.004 m/s.

After the two previous factors that affect the muzzle velocity, a new range is calculated based on the modified muzzle velocity and then the following factors are applied. They impact the range and/or the deflection.

(3) Projectile Weight. Weight in projectiles is represented with red squares drawn on the body of it. Four squares is the standard factory weight. Any deviation, whether a lower or bigger weight, is represented with less or more squares respectively. The difference (in squares) from the standard weight impacts the range. In our model, a factor of 4 meters per square is used. First, the weight of the projectile is randomly calculated with the following being assumed:

- 80%, 4 squares (standard weight)
- 15%, 5 squares (heavier)
- 5%, 3 squares (lighter)

(4) Wind. The wind speed and direction affect the projectile during its flight towards the target, and subsequently, they affect the location of the impact. For calculating the size of affection, the wind is converted into two elements; one

[2] Measured in m/s (meters per second).

parallel and one perpendicular to the direction of the projectile. The parallel element has an impact on the range (less or more), while the other has an impact on the deflection (left or right). In our model, the two elements are chosen by taking random measurements for the speed in the range from 0 to 9 knots, and also for the direction, head or tail for the parallel, and left or right for the perpendicular. Firing tables give corrections for each 500 meters of range for the four different types of wind (head, tail, left or right). In our model, the following sizes of impact are selected.

- Head wind: Add 0.5 meters in range per each 500 meters of range.
- Tail wind: Subtract 0.2 meters in range per each 500 meters of range.
- Left wind: Add 0.02 mils[3] in azimuth per each 500 meters of range.
- Right wind: Subtract 0.02 mils in azimuth per each 500 meters of range.

(5) Dispersion. This is the phenomenon that projectiles from a single gun will tend to deviate over a rectangular or elliptical area whose longer axis is along the line between the gun and the target. The dispersion rectangle is divided evenly into eight zones in range. The size of each zone is called Probable Error in Range (PER). Similarly, the rectangle is divided into eight zones in the other dimension. The size of each zone is called Probable Error in Deflection (PED). The percentage of rounds impacting within each zone has been determined through experimentation as described in Appendix B. In our model, a normal distribution is used to describe this situation for each dimension. The number of projectiles along the longer axis is distributed normally with a mean of zero (0) and a standard deviation of length over 8. The result of this distribution has an impact on the range. The number of projectiles along the other axis is distributed normally with a mean of zero (0) and a standard deviation of width over 8. The result of this distribution has an impact on the azimuth.

By applying all the above factors in our model, a new range and a new azimuth for the current target results, which in turns provides a new location of impact. This location is transmitted to the FOPCSIM application with the Shoot message.

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[3] Mils are used in the artillery for angle measurement. One circle has 6400 mils.

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V. CONCLUSIONS AND FUTURE WORK

A. SUMMARY

This thesis implemented a software application, which together with the FOPCSIM application, will comprise a complete training system for the forward observer of the artillery. Some tasks and default actions of the FOPCSIM application are performed now in the FDC application environment providing more realistic results and giving more feedback to the training system.

The existence of another user, the user of FDC application, provides another dimension to the FOPCSIM training. The trainee is now aware of the FDC application and knows that his call for a fire procedure will not be simple and standard. He also knows that his call for fire will be rejected or modified by the FDC depending on various elements such as munitions availability, battery condition and so forth.

The network connection between the two application with all the consequences that are implied (network delays, missing messages, disconnection etc.) creates a realistic training environment. It has been proven in real training that many times communication problems have prevented the conduct of a smooth and error-free training procedure. Thus, the forward observer must be aware of these conditions in order to be prepared to deal with such situations.

Another important element of the FDC application is the feedback given to the forward observer by keeping track of each mission's information. The trainee has the ability to review his mission after it has been completed. He can examine his transmissions and extract useful conclusions about his procedures, the mistakes he made, and how to improve his overall performance.

B. FUTURE WORK

The FDC application can be modified and extended in various ways and are discussed below.

1. Network Performance

The underlying network tool (gfNetwork) provides a simple and very effective way for creating a connection between two or more applications. However, there can be

some improvements in its performance. In the current implementation, the connection is a peer-to-peer connection with the FDC acting as a host and the three FOPCSIM instances as clients. If the host (FDC) goes down then the entire session is closed and must be re-instantiated. DirectPlay provides the feature of host migration which can be implemented in this case. Thus, when the host goes down, another client becomes the host, and the session remains open. Then, only the FDC application must be connected again to continue the training procedure.

Another improvement to be made is the network responses,when a node is down. In the current implementation, the delay is defaulted to 60 seconds which is a rather long time to wait for a response. This can be decreased to a more appropriate time delay in order to create a more convenient system.

2. Battery Procedures

The conventional artillery consists of three basic elements. The forward observer, which acts as the “eyes”, the Fire Direction Center, which is the “mind”, and the battery platoons which provide the fire. The two, forward observer and Fire Direction Center, are provided with the current system. Another system can be implemented to describe and perform the battery procedures. This system will communicate with the FDC application receiving fire orders and performing the actual firing. The firing can be performed in real-time using a more complete ballistic model and follows the trajectory of the projectile towards the target. The location of the impact will not pre-computed but it will be the location where the projectile will hit the ground. The VEGA® application provides this possibility by using Isectors.

APPENDIX A. SAMPLE MISSIONS

The following are sample calls for fire and FDC responses for various type missions.

Observer	FDC
Z57 THIS IS Z71, ADJUST FIRE, OVER.	
	THIS IS Z57, ADJUST FIRE, OUT.
GRID NK180513, OVER.	
	GRID NK180513, OUT.
INFANTRY PLATOON IN THE OPEN, ICM IN EFFECT, OVER.	
	INFANTRY PLATOON IN THE OPEN, ICM IN EFFECT, AUTHENTICATE PAPA BRAVO, OVER.
I AUTHENTICATE CHARLIE, OUT.	
	Z, 2 ROUNDS, TARGET AF1027, OVER.
Z, 2 ROUNDS, TARGET AF1027, OUT. DIRECTION 1680, OVER.	
	DIRECTION 1680, OUT.

Table 1. Fire Mission (Grid)

Observer	FDC
H66 THIS IS H44, ADJUST FIRE, SHIFT AA7733, OVER.	
	THIS IS H66, ADJUST FIRE, SHIFT AA7733, OUT.
DIRECTION 5210, LEFT 380, ADD 400, DOWN 35, OVER.	
	DIRECTION 5210, LEFT 380, ADD 400, DOWN 35, OUT.
COMBAT OP IN OPEN, ICM IN EFFECT, OVER.	
	COMBAT OP IN OPEN, ICM IN EFFECT. AUTHENTICATE LIMA FOXTROT, OVER.
AUTHENTICATE PAPA, OUT.	
	H, 1 ROUND, TARGET AA7742, OVER.
H, 1 ROUND, TARGET AA7742, OUT.	

Table 2. Fire Mission (Shift)

Observer	FDC
Z56 THIS IS Z31, FIRE FOR EFFECT, POLAR, OVER.	
	THIS IS Z56, FIRE FOR EFFECT, POLAR, OUT.
DIRECTION 4520, DISTANCE 2300, DOWN 35, OVER.	
	DIRECTION 4520, DISTANCE 2300, DOWN 35, OUT.
INFANTRY COMPANY IN OPEN, ICM, OVER.	
	INFANTRY COMPANY IN OPEN, ICM, AUTHENTICATE TANGO FOXTROT, OVER.
I AUTHENTICATE ECHO, OUT.	
	Y, VT, 3 ROUNDS, TARGET AF2036, OVER.
Y, VT, 3 ROUNDS, TARGET AF2036, OUT.	

Table 3. Fire Mission (Polar)

Observer	FDC
H18 THIS IS H24, SUPPRESS AB3104, OVER.	
	THIS IS H18, SUPPRESS AB3104, AUTHENTICATE DELTA JULIET, OVER.
I AUTHENTICATE DELTA, OUT.	

Table 4. Fire Mission (Suppression)

Observer	FDC
H18 THIS IS H24, IMMEDIATE SUPPRESSION, GRID 211432, AUTHENTICATION IS TANGO UNIFORM, OVER.	
	THIS IS H18, IMMEDIATE SUPPRESSION, GRID 211432, OUT.

Table 5. Fire Mission (Immediate Suppression)

APPENDIX B. BALLISTICS

A. INTRODUCTION

Ballistics is the study of the firing, flight, and effect of ammunition. A fundamental understanding of ballistics is necessary to comprehend the factors that influence precision and accuracy and how to account for them in the determination of firing data. To ensure accurate predicted fire, we must strive to account for and minimize those factors that cause round-to-round variations, particularly muzzle velocity. Ballistics can be broken down into four areas: interior, transitional, exterior, and terminal.

B. INTERIOR BALLISTICS

This science deals with the factors that affect the projectile inside the tube and determine the muzzle velocity. This is the velocity of the projectile just when it leaves the muzzle of the tube. Firing tables give the standard muzzle velocity per projectile, propellant and tube type. Of course, each velocity differs from time to time due to various reasons. Tube wear, propellant efficiency and projectile weight are the items that are normally accounted for in determining muzzle velocity.

C. EXTERIOR BALLISTICS

This science studies the behavior of the projectile after it has left the muzzle of the tube until it will hit the ground. Some of the deviations from standard conditions affecting the motion of the projectile and subsequently the location of the impact are the following:

- Muzzle velocity.
- Projectile weight.
- Wind.
- Air temperature.
- Air density.
- Rotation of the earth.
- Drift.

D. DISPERSION

Another element that determines the location of the impact is dispersion. If a number of rounds of ammunition of the same caliber, lot, and charge are fired from the same position with identical settings used for deflection and quadrant elevation, the rounds will not all impact on a single point but will fall in a scattered pattern. In discussions of artillery fire, this phenomenon is called dispersion, and the array of bursts on the ground is called the dispersion pattern, as shown in Figure 14.

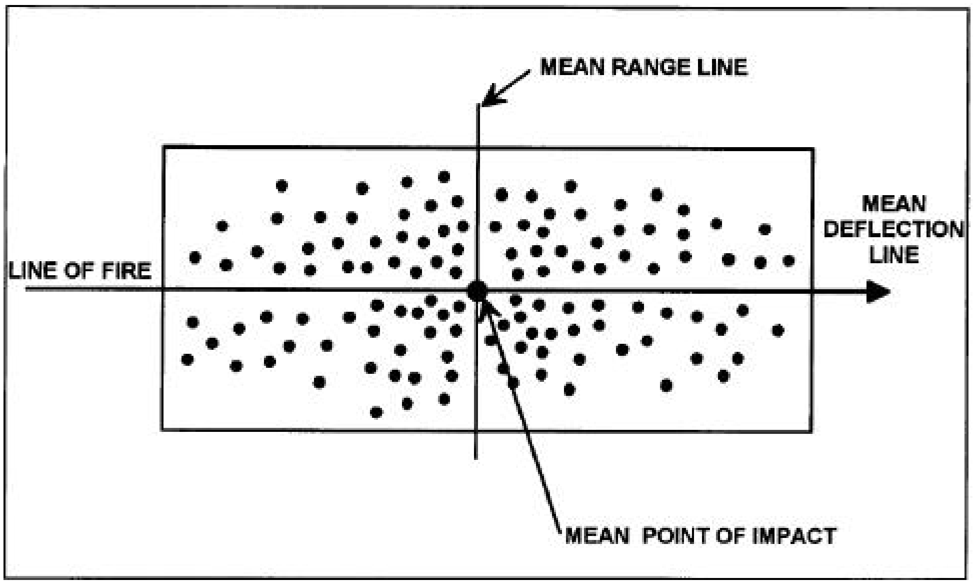

Figure 14. Dispersion Rectangle (From: FM 6-40)

If the dispersion rectangle is divided evenly into eight zones in range, the percentage of rounds impacting within each zone is as indicated in Figure 15. The percentage of rounds impacting within each zone has been determined through experimentation. The size of each zone is called Probable Error in Range (PER). By definition of probable error, 50 percent of all rounds will impact within 1 probable error in range or deflection of the mean point of impact (25 percent over and 25 percent short).

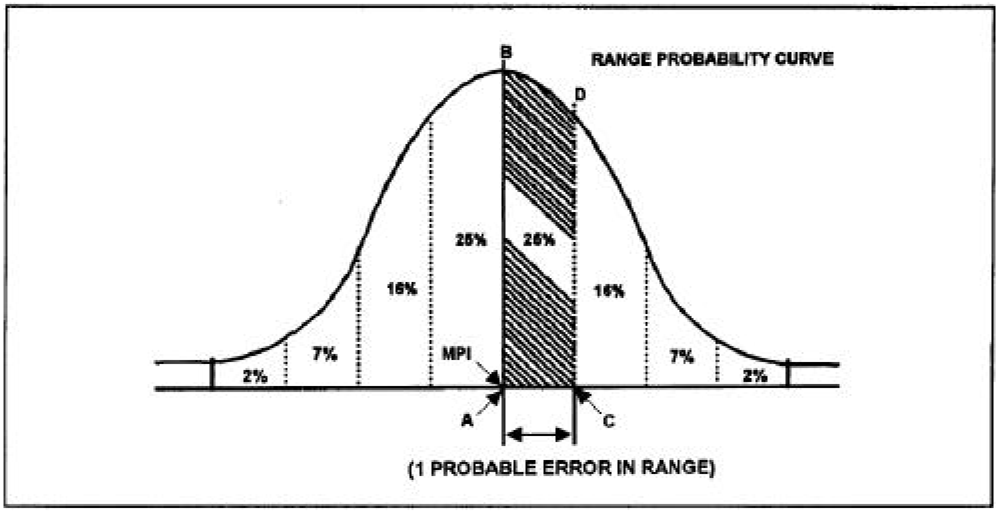

Figure 15. Probable Error Distribution for Range (From: FM 6-40)

Similarly, there is a zone distribution in the other dimension of the rectangle. This introduces the Probable Error in Deflection (PED). The values of these errors in each combination of ammunition / charge are listed in the artillery firing tables.

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APPENDIX C. GLOSSARY

Adjust fire	A method of control transmitted in the call for fire by the observer that indicates he will control the adjustment of the rounds to the target.
Angle T	The interior angle formed at the target by the intersection of the observer-target and the gun-target lines.
Ballistics	The science or art that deals with the motion, behavior, appearance, or modification of missiles or other vehicles acted upon by propellants, wind, gravity, temperature, or any other modifying substance, condition, or force.
FDC	Fire Direction Center
FDO	Fire Direction Officer
FO	Forward Observer
FOPCSIM	Forward Observer Personal Computer Simulation
MTO	Message to Observer
Muzzle velocity	The velocity of a projectile at the instant the projectile leaves the muzzle of the weapon.
Observation post	A position which possesses the appropriate communications and other equipment, make military observations, and from which fire is directed and adjusted onto targets.
RATELO	Radiotelephone Operator
Round	One shot expended by a weapon.
Time of flight	The time in seconds from the time a projectile leaves the muzzle until it bursts.

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BIBLIOGRAPHY

[1] David Brannon and Michael Villandre (2002). *The Forward Observer Personal Computer Simulator (FOPCSIM).* Naval Postgraduate School, Master's Thesis, Monterey, California.

[2] MultiGen-Paradigm Inc. (2000), *Vega Programmer's Guide, Version 3.5 for Windows NT and Windows 2000*.

[3] Michael Sweet, Craig P. Earls, and Bill Spitzak (2003). *FLTK 1.1.3 Programming Manual, Revision 4*. GNU Library General Public License.

[4] U.S. Army Doctrinal Publication (1990). *FM 6-20-1. The Field Artillery Cannon Battalion*, Headquarters Department of the Army, Washington, D.C.

[5] U.S. Army Doctrinal Publication (1991). *FM 6-30. Tactics, Techniques, and Procedures for Observed Fire*, Headquarters Department of the Army, Washington, D.C.

[6] U.S. Marine Corps Doctrinal Publication (1996). *FM 6-20-10/MCRP 3-1.6.14. The Targeting Process*, Headquarters Department of the Army, United States Marine Corps, Washington, D.C.

[7] U.S. Marine Corps Doctrinal Publication (1996). *FM 6-40/MCWP 3-1.6.19. Tactics, Techniques, and Procedures for Field Artillery Manual Canon Gunnery*, Headquarters Department of the Army, United States Marine Corps, Washington, D.C.

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